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(71) Applicant:
TEMIC TELEFUNKEN microelectronic GmbH, 74072 Heilbronn, DE; Continental Aktiengesellschaft, 30165 Hannover, DE
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(54) System to determine the operating parameters of vehicle tyres

(57) A system to determine the operating parameters of vehicle tyres is described, with:

a) a carrier unit integrated in the tyre with two carrier bodies and a separator disposed in between,
b) a sensor unit disposed in the tyre or on the carrier body (bodies) with at least one detector and one electronic eevaluation unit,
c) a piezoelectric element which is placed on one of the carrier bodies and which serves as electrical energy supply for the system components and as sensor for the tyre rotations,
d) an integrated semiconductor switching circuit, disposed on one of the carrier bodies with an electrical energy supply unit, a count unit, a control unit, a temperature evaluation unit, a storage unit and an output unit,
e) a data transmission unit disposed on one of thc carrier bodies.

Description

A continuous, automatic determination of the operating parameters of vehicle tyres – e.g. temperature, extension/tension and tyre pressure - is desirable for many applications. In addition, a reliable and manipulation-safe identification of each tyre and the registration of the performance must be guaranteed.
For the last mentioned application, a rotation counter, disposed in the tyre, is known from DE-OS 30 44 149, which captures the number of rotations with a piezoelectric sensor, shaped as a film, and stores the data in a counter register; the data are transmitted towards the outside with a contactless interface. An identification code can be stored in another register, which enables a re-identification. Said rotation counter, however, needs a battery for the electrical energy supply of its components, which results in a limited life, a great assembly volume and a limited range of temperature (especially during the manufacturing process of the tyre).
In addition, systems are known (e.g. from DE-OS 40 02 566 and DE-OS 34 07 254) where mechanical energy is transformed in electrical energy by using the tyre movement or the incitement by the road, using piezoelectric or inductive methods. Said known systems can be used, however, only in the wheel rim and not in the tyre, because of their construction (great assembly volume);

they are, therefore, not enough protected against manipulations and an insufficient functional reliability can be expected.
This invention relates to the objective to provide a system to determinate the operating parameters of vehicle tyres with a simple structure, which avoids the abovementioned disadvantages and comprises advantageous properties.
This objective is achieved, according to the invention, by the features a) to e) of claim1.
Advantageous further developments of the invention will be apparent from the dependent claims.
The contemplated system for determination and contactless data inquiry of the operating parameters of the tyre with an independent electrical energy supply is integrated as a unit into the tyre structure during the manufacturing process. It consists of:

a) a carrier unit with two carrier bodies (made of Al_2O_3 ceramics, for instance) to receive the system components; between the two carrier bodies, a separator made from a material of medium stiffness (e.g. silicone, cured) is disposed to absorb or reflect the undesired hydrostatic compressive strain which acts perpendicular with respect to the pressure-sensitive axis of the piezoelectric element;
b) a sensor unit with one or more sensors and the appropriate analysing electronic devices for the capture or the detection, respectively, of the desired operating parameters and the preparation of the measuring signals;
c) a (preferably single) piezoelectric element for electrical energy supply of the system components (the hydrostatic compressive strain of the tyre rubber is induced by the carrier bodies into the piezoelectric element, in parallel direction with respect to its pressure-sensitive axis); simultaneously, the piezoelectric element function as a "rotation sensor" to detect the tyre rotations (if only the performance has to be determined, no additional sensors are required);
d) an integrated electrical circuit (IC chip) to analyse and store the determined parameters and the tyre rotations: the IC comprises an electrical energy supply unit, a count unit to determine the number of tyre rotations, a control unit to control the time history and the logical flow, a unit for the capture and the evaluation of temperature load, a storage unit and a non-volatile, electrical erasable storage, writeable during stop of the tyre (E^2PROM), as well as an output unit to read the stored data by means of a transponder. Because there are a great number of storage processes during the use of the system, the write cycles are distributed uniformly among all storage cells by the control unit which carries out a rotation of the counter location during the storage process, so that the recording load of the storage cells are distributed uniformly. In addition, several storage cells are described redundantly with the same information, wherein the operatability of the storage is maintained also by failure of single storage cells by means of an automatic error correction carried out by the control unit;
e) a passive transponder (consisting of transponder circuit, transponder coil and resonance capacitor) for data transmission of the operating parameter and for identification of the tyre; the stored information by the transponder can be read with an external reading device.

The above described system encompasses several advantages:

- any tyre parameters can be determined, stored and read, whereby particularly the determination of the tyre performance is possible in a simple way and without additional detectors or sensors,
- it is completely independent, because the electrical energy supply is produced exclusively by the piezoelectric element,
- because of its structure with carrier bodies and separator, the compressive strain is brought very effectively to the piezoelectric element and thus its performance is increased,

- it presents only few system components and no mechanically moved parts and so the structure results simple and less prone to faults,
- a high reliability is guaranteed, by reducing the write rate in the storage cells, very much subjected to strain, by the redundant description of the storage cells and by the simple and efficient error correction processes,
- by integration in the tyre (the system is connected inseparably with the tyre and therefore not accessible from the outside) it is safe against manipulation.

With the help of figures 1 and 2 a system for determination of the performance of a vehicle tyre with simultaneous acquisition of the temperature strain and simultaneous possibility of identification is described, as an exemplifying embodiment.

Figure 1 shows the system structure (Fig. 1a in top view, Fig. 1b in cross section, Fig. 1c in side view) and figure 2 shows a modular mimic display with the functional units of the system.

a) Electric energy supply/counting of the tyre rotation

For electric energy supply of the system components and, simultaneously, as detector for the tyre rotations, a single piezoelectric element 30, preferably constructed with multi-layer technology, is used as follows:

- Electric energy supply: During the rotation process of the tyre and with the aid of the piezoelectric element 30, disposed on the carrier body 11 (e.g. made of Al_2O_3), electric energy is produced from the compressive strain in the tyre rubber which changes cyclically (piezoelectric effect): At a perpendicular pressurization of the piezoelectric element 30, its outer surfaces 31, which lie parallel to the pressure direction, are curved barrel-shaped towards the outside in microscopic dimensions. As the hydrostatic pressure, however, opposes the bulging and, therefore, limits drastically the performance of the piezoelectric element 30, a separator 12 is disposed between carrier body 11 and carrier body 12, which absorb or reflect the hydrostatic compressive strain. The stiffness of the separator material is adjusted so that the compression set of the piezoelectric element (ceramics with extremely high stiffness) is not diminished and, at the same time, the absorbing or reflecting effect on the hydrostatic compressive strains, deriving from the sides, is maintained. The pressure sensitive surfaces are enlarged by carrier bodies 11, 12 with high stiffness (e.g. metal, ceramics), leading a higher compressive strain into the piezoelectric element 30 and so increasing its performance. The alternating voltage at the electrodes of the piezoelectric element 30 is transformed into direct voltage by the rectifier circuit of the integrated circuit.
- Tyre rotation detector: At each rotation of the tyre, a pulse signal is produced by the piezoelectric element 30, which serves as basis for the rotation counting. For recording, analysing and storage of the tyre rotation information, the exit of the piezoelectric element 30 is connected with an integrated circuit 40 (IC chip), which is disposed on the carrier body 11, which comprises, according to figure 2, an energy supply unit 41, a count unit 42, a control unit 43, a storage unit 44, a temperature evaluation unit 46 and an output unit 45. Each tyre rotation is recorded in the count unit 42 of the IC chip 40; one electrode (one exit) of the piezoelectric element 30 is connected with the count unit 42, which has a counter register at its exit for further processing. When the vehicle stops (no more tyre rotation), the electric energy supply by the piezoelectric element 30 is interrupted and the current counter value is stored in a E^2PROM storage of the storage unit 44. When the tyre movement starts again, the current value, stored in the E^2PROM storage, is loaded into the count

unit 42 and the rotation counting is continued. With the control unit 43, the maximum number of data modifications in the E^2PROM storage cells are reduced and an automatic error correction is carried out.

b) Temperature load

The temperature load of the vehicle tyre is determined by the temperature evaluation unit 46, which is preferably a component of the integrated circuit 46, measuring the current rubber temperature at each tyre rotation and evaluating it as a function of the covered distance (captured by the tyre rotation detector). When the tyre stops (no more tyre rotation), the criterion of evaluation, until then significant for the covered distance, is stored in a E^2PROM storage of the storage unit 44. When the tyre movement starts again, the until then significant criterion of evaluation, stored in the E^2PROM storage, is recovered in the temperature evaluation unit 46 and used as basis for the generation of the new criterion.

c) Data transmission

For the data transmission, the stored information is transmitted towards the outside by means of the output unit 45, the transponder unit 51 and the transponder coil 52 and can be read with a handheld reader, which provides an inductive alternating field for electric energy supply. The capacitor 53 serves as resonance capacitor to tune to the transmission frequencies.

According to figure 2 the single functional units of the integrated circuit 40 can be sub-divided as follows:

a) Electric energy supply unit 41 (operating voltage unit 41a, programming voltage unit 41b): The (operating) distribution voltage for the integrated circuit 40 (DC voltage of e.g. 3 V) is powered with the power supply unit 41a and the capacitor 41c, the programming voltage for the E^2PROM storage cells 44b (DC voltage of e.g. 12 V) is powered with the power supply unit 41b and the capacitor 41d, whereby the electrical energy (alternating voltage) is supplied from the piezoelectric element 30, which functions as external source of energy.
b) Count unit 42 (pulse detector 42a, pre-divisor 42b, counter 42c): With the pulse detector 42a, each negative or positive side of an impulse, generated by the piezoelectric element 30, is detected as a signal for a tyre rotation. For a better processing of the rotation information (reduction to a practicable resolution), the data of the pulse detector 42a are divided by a determined factor (e.g. by the factor 2^{10}) with the pre-divisor 42b which is developed as a decrementer; at a stop of the tyre, the counter 42c, preferably developed as a binary counter, transmits its count value to the storage unit 44 and, when the tyre movement starts again, it is pre-loaded with the value stored there.
c) Control unit 43 (voltage level detector 43a, check unit 43b, coder/decoder 43c): To avoid data loss during very slow tyre rotation, a signal is generated by the voltage level detector 43a when the distribution voltage remains under a certain limit count, by which the storage unit 44 is induced to store the current count of the counter. Control signals are generated by the check unit 43b, by which the chronological and logical processes of the different functional units of the IC chip are checked, monitored and coordinated (initialization, detection of the electric energy supply, counting mode, writing mode, reading mode, programming mode, output mode, temperature capture etc.). To reduce the number of data changes in the E^2PROM storage cells 44b, a coding (rotation) of the counter bits or of the different counter bit groups (exclusively of the less high ones) are carried out by the coder/decoder unit. The counter bits are distributed in the single counter bit groups, so that the medium bit change probability of all bits of a group is as small as possible and is as

cqual as possible in all groups. Thus, the information about the number of rotation steps is obtained from the non-rotated counter locations: a preset number of significant counter bits is used to define the position of the groups, the other bits are rotated, whereby the rotation is carried out before each writing cycle into the E^2PROM storage cells 44b. Rotated and not-rotated counter locations are deposited in the storage cells of the E^2PROM storage 44b. The retrieval of the correct count of the counter (decoding) – when the tyre rotation count starts again – takes place in the opposite way: the non-rotated counter locations indicate how many steps the other (rotated) storage cells have to be rotated back so that the binary counter 42c can be loaded with the current value. With this rotation of the storage cells (the number of steps does not almost change with the increse of the count of the counter), a uniform recording load of all storage cells is obtained. As coder/decoder 43c, a switching matrix, consisting of single bidirectional gates, is preferably used so that neither additional storage locations nor a microcontroller is necessary to carry out the rotation.
The coder/decoder 43c, for instance, is made as 1/N decoder with a (static) switching matrix made of bidirectional transmission gates, whereby the coding/decoding can be interpreted in different ways, in dependence of the number of counter locations (counter bits), of the desired reduction of the write cycles and of the available circuit surface on the IC chip: In a 20-bit binary counter 42c, for instance, by the means of a switching matrix 43c, 16 bits are rotated from 16 x 16 gates, while the four bits with the highest value supply the rotation information; in a 22.bit binary counter 42c, for instance, by the means of a switching matrix 43c, 20 bits are gathered in five groups of 4 bits from 4 x 20 bidirectional gates, while the two counter bits with the highest value supply the rotation information – the rotation itself is here carried out within each group.

d) Storage unit 44 (read/write logic) for performance 44a, storage cells unit 44b, read/write logic for temperature load 44c):
With the read/write logic 44a, the tyre rotation information, coded because of the rotation of the counter locations of the binary counter 42c, is transferred from the coder/decoder unit 43c to the storage cells unit 44b, when the tyre rotation starts or stops. To increase the reliability of the system, the storage cells unit are divided in groups containing a determined number of E^2PROM storage cells (e.g. 3 storage cells each), the same counter bit being stored in each group at the same time, whereby, in addition, a determined number of storage cell contents can be inverted in each group (e.g. one storage cell contents out of three storage cell contents) to increase reliability. As a result of this, a simple check of the stored information is possible with a simple logic (e.g. three AND gates and one OR gate: that value is put out as correct, which is contained in the majority of the storage cells of the group (e.g. in two of the three storage cells); consequently a certain number (e.g. one out of three) of the storage cells of a group can be faulty without creating a loss of information (this is important for the measuring of the performance with the tyre rotation counting, because there are necessary a high number of write cycles and because the probability of a fault increases with the number of write cycles). The read/write logic 44c transfers the data for the temperature evaluation from the unit for temperature evaluation 46 to the storage cell unit 44b. The data transfer is controlled by the check unit 43b. In figure 2 the storage of the temperature evaluation is represented, for better clarity, without appropriate measures for distribution of the write cycles and without redundant arrangement of the storage cells for error correction, but the abovementioned measures for distribution of the write cycles and for error correction can be applied, if required, also on the data of temperature evaluation.
The read/write mode for the storage unit 44 is monitored by the check unit 43b: a programming of the E^2PROM storage cells 44b is carried out only when the new contents of a storage cell differs from the existing contents (the check unit 43b initializes the programming process with a control signal), whereby the programming voltage is supplied by the programming voltage source 41b of the distribution voltage unit 41.

c) Data output (output unit 45, transponder 50):
To transmit the tyre rotation information towards the outside, a digital transponder interface is used as output unit 45. As there is no energy supplied by the piezoelectric element 30 during reading out of the data, all system components necessary for reading out (check unit 43b, read/write logic 44a, 44c, E^2PROM storage 44b, transponder interface 45) have to be powered by the means of an inductive alternating field. Preferably the transponder unit 51 can also be integrated into the electric circuit 40. The reading out is initialized by the transponder 50 with a control signal and monitored by a check unit 43b. During the operating modus (tyre rotation counting), the transponder interface 45 is switched off for power saving.

f) Temperature evaluation unit 46 (temperature sensor 46a, AD transducer 46b, evaluation unit 46c):
The temperature sensor 46a captures constantly the temperature T of the tyre rubber in its surroundings; it is preferably a semi-conductor sensor and is part of the integrated circuit 40. The electric output signal of the temperature sensor 46a (e.g. a change of voltage or resistance) is converted, controlled by the check unit 43b, preferably into a binary code by the analogue digital conversion unit (ADU) 46b; the data conversion is preferably carried out at each tyre rotation. The output register of the ADU is an erasable adder. During a determined covered distance, which is inferred, for instance, from the period of the output signal of the pre-divisor, the single ADU- measured values are added up with an adding value. The capacity of the accumulating register is so dimensioned that there will be no register overflow during a period of the pre-divisor signal. At the end of a pre-divisor period, the significant contents of the accumulating register, controlled by the check unit 43b, are transferred into the evaluation unit 46c and then the contents of the accumulating registers are zeroized. With each further pre-divisor period the process is repeated cyclically. If the pre-divisor has a measure of 2^{10} and the word length of each ADU-measurement is 8 bit, the accumulating register has a length of 18 bit to avoid an overflow during the pre-divisor period. At the end of each pre-divisor period the 8 bits with the highest value (11 to 18) are transmitted as significant result to the evaluation unit 46c. The result represents so the medium value of the temperature signal during the pre-divisor period.
The evaluation unit 46c adds up the arithmetic temperature medium values after each pre-divisor period in a evaluation register. During a stop of the tyre, the contents of the evaluation register is transmitted, controlled by the check unit 43b, to the storage unit 44. When the tyre movement starts again, the evaluation register is pre-loaded with the last stored value of the criterion of evaluation.

Claims:

1. System for the determination of the operating parameters of vehicle tyres, consisting of:
   a) a carrier unit (10), integrated in the vehicle tyre, with two carrier bodies (11, 12) and a separator (13) disposed in between,
   b) a sensor unit (46) placed in the vehicle tyre or on the carrier body (bodies) (11, 12) with at least one detector (46a) and one electronic evaluation unit (46b, 46c),
   c) a piezoelectric element (30), placed on one of the carrier bodies (11), which serves for electrical energy supply of the system components and as sensor for the tyre rotations
   d) an integrated semiconductor switching circuit (40), disposed on one of the carrier bodies (11) with an electrical energy supply unit (41), a count unit (42), a control unit (43), a storage unit (44), a temperature evaluation unit (46) and an output unit (45),
   e) a data transmission unit (50) placed on one of the carrier bodies (50).

2. System according to claim 1, characterized in that the carrier bodies (11, 12) consist of a ceramic material.

3. System according to claim 2, characterized in that the carrier bodies (11, 12) consist of aluminium oxide or aluminium nitride.

4. System according to one of the claims 1 to 3, characterized in that the separator (13) is disposed on the edge of the carrier bodies (11, 12).

5. System according to claim 4, characterized in that the separator (13) is made from a material of a determined stiffness, which is lower than the stiffness of the piezoelectric element (30) and greater than the stiffness of the surrounding tyre rubber and therefore great enough to hold lateral compressive strain away from the piezoelectric element (30).

6. System according to one of the claims 1 to 5, characterized in that the piezoelectric element (30) has a multi-layer structure.

7. System according to one of the claims 1 to 6, characterized in that the piezoelectric element (30) is connected with the electrical energy supply unit (41) and the input port of the count unit (42).

8. System according to one of the claims 1 to 7, characterized in that the electrical energy supply unit (41) consists of an operating voltage unit (41a) and a programming voltage unit (41b) with external storage capacitors (41c, 41d).

9. System according to one of the claims 1 to 8, characterized in that the count unit (42) has a pulse detector (42a), a pre-divisor (42b) and a counter (42c).

10. System according to one of the claims 1 to 9, characterized in that the control unit (43) has a voltage level detector (43a), a check unit (43b) and a coder/decoder (43c).

11. System according to one of the claims 1 to 10, characterized in that the storage unit (44) has a read/write logic (44a, 44c) and a E^2PROM storage (44b) with storage cells.

12. System according to one of the claims 1 to 11, characterized in that the E^2PROM storage (44b) is divided in groups with several storage cells each, which are described jointly at each storage process.

13. System according to claims 11 or 12, characterized in that the storage cells of the E^2PROM storage (44b) are only describable, when the value to be stored differs from the current contents of the storage cells.

14. System according to one of the claims 1 to 13, characterized in that the coder/decoder (43c) is a switching matrix made from bidirectional transmission gates, by which is carried out the rotation of the counter locations during read/write of the E^2PROM storage (44b).

15. System according to one of the claims 1 to 14, characterized in that the read/write logic (44a, 44c) has gates which are linked and therefore, during the storage process, the contents of a determined number of storage cells of each group are inverted and, during the reading process, the contents of the storage cells is checked.

16. System according to one of the claims 1 to 15, characterized in that the temperature evaluation unit (46) has a temperature sensor (46a) to capture the tyre temperature, an analogue-to-digital transducer (46b) for digitalisation and averaging of the signal of the temperature sensor and a evaluation unit (46c) for evaluation of the averaged measure results.

17. System according to one of the claims 1 to 16, characterized in that the data transmission unit (50) is a transponder circuit (51) with a coil (52) and a resonance capacitor (53) and that the data transmission unit (50) is connected with the output unit (45).

18. System according to claim 17, characterized in that the data transmission unit (50) is integrated into the integrated semiconductor circuit (40).

19. System according to one of the claims 1 to 18, characterized in that the data transmission unit (50) has a storage, where are planted data for the identification of the tyre.